Standard Penetration Test measurement variations exposed using a Digital PDM device

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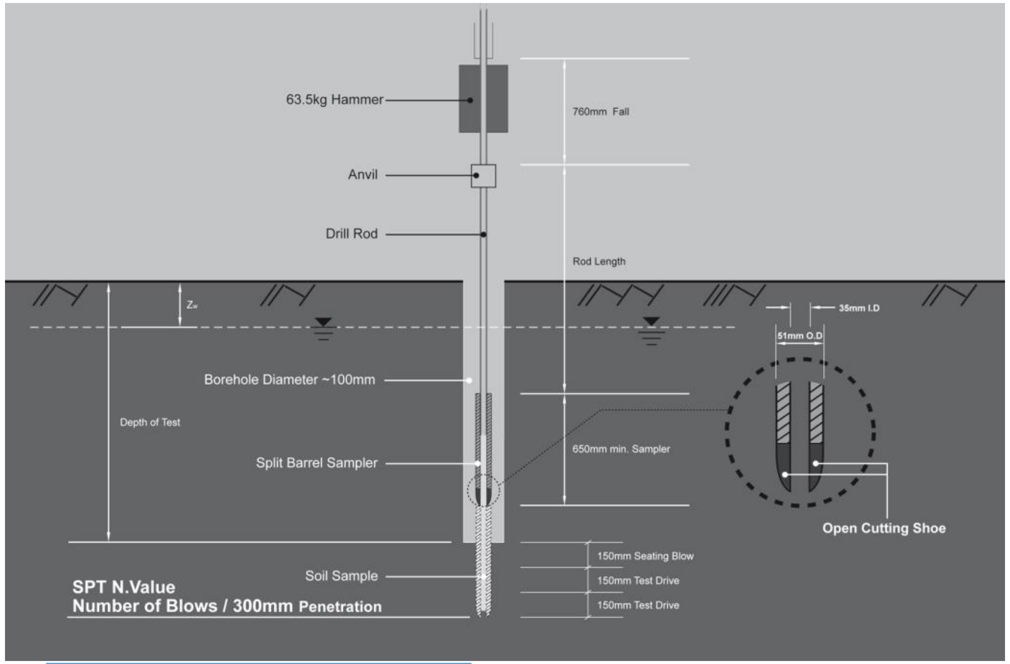
Content



SPT circa 1940s

- Counting Blows
- Corrections Required

PDM circa 2010

- Set
- Energy

PDM +SPT

- Test Sites
- Results

Key findings

- Blow count @ 150mm is an estimate and not "factual". Seating is not an "exact" 150mm
- University trained supervisors are unable to count above 20 accurately
- Energy varies
  - with ground conditions
  - with each blow
  - with depth

Judgement Time to decide on blow increment

In carrying out the SPT, typically

- 0.2 seconds for the hammer falling
- < 0.05 second to come to a standstill (temporary compression occurs here),
- < 5 seconds before the next below is delivered

The accuracy of the drilling supervisor's assessment in that time frame is examined.

With some automatic hammers the time can be less than 1 second between blows.

Which is your favourite Correction Factors reference ?

Corrections proposed by Bowles (1996)

Factor	Variable	Term	Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Rope and Pulley Donut Hammer	n1	1.14 – 1.42* 1 – 1.14* 0.64*
Rod Length (meters)	Length '10 m+ (100 ft+) '6 – 10 m (20 – 30 ft) '4 – 6 m (13 – 20 ft) '0 – 4 m (10 – 13 ft)		 1 0.95 0.85 0.75
Sampler	Without liner With liner: dense sand, Clay With liner: loose sand		1 0.8 0.9
Bore Hole Diameter	'60 – 120 mm (2.5 – 4.5 in) '150 mm (6 in) '200 mm (8 in)		1 1.05 1.15

* where n1=(Er/70) example for ER = 80% – 100% n1 = 1.14 – 1.43

Corrections proposed by Robertson and Wide (1997)

Factor	Variable	Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Donut Hammer	0.8 – 1.5 0.7 – 1.2 0.5 – 1.0
Rod Length (meters)	Length over 30 m (100 ft) '10 – 30 m (30–100 ft) '6 – 10 m (20–30 ft) '4 – 6 m (13–20 ft) '3 – 4 m (10–13 ft)	Less than 1 1 0.95 0.85 0.75
Sampler	Without liner With liner: dense sand, Clay With liner: loose sand	1.1 – 1.3 1 1
Bore Hold Diameter	'60 – 120 mm (2.5 – 4.5 in) '150 mm (6 in) '200 mm (8 in)	1 1.05 1.15

Corrections proposed by Skempton (1986)

Factor	Variable	Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Donut Hammer	None listed 0.9 0.75
Rod Length	Length over 10 m (over 30 ft) '6 – 10 m (20 – 30 ft) '4 – 6 m (13 – 20 ft) '3 – 4 m (10 – 13 ft)	1 0.95 0.85 0.75
Sampler	Without liner With liner: dense sand, Clay With liner: loose sand	1.2 1.0 1.0
Bore Hole Diameter	'60 – 120 mm (2.5 – 4.5 in) '150 mm (6 in) '200 mm (8 in)	1 1.05 1.15
Anvil Size	Small Large	0.6 – 0.7 0.7 – 0.8

Corrections proposed by Seed (1984) per McGregor and Duncan (1998)

Factor	Variable	Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Donut Hammer	1.67 1 0.75
Rod Length (meters)	Over 10 m (+30 ft) '6 – 10 m (20 – 30 ft) '4 – 6 m (13 – 20 ft) '3 – 4 m (10 – 13 ft) '0 – 3 m (0 – 10 ft)	1 1 1 1 0.75

Tables from Agour and Radding (2001)

Hiley Pile Driving Formula

Dynamic analysis of pile capacity is carried out using wave analysis or approximate methods such as a pile driving formulae → Transfer of the kinetic energy from falling pile hammer to the pile + soil. Loss of energy due to temporary compression + mechanical friction losses. The Hiley pile driving formula is commonly used.

Ultimate capacity of pile $(R) = (e\, W\, H)/(s + c/2)$ .... Hiley Formula

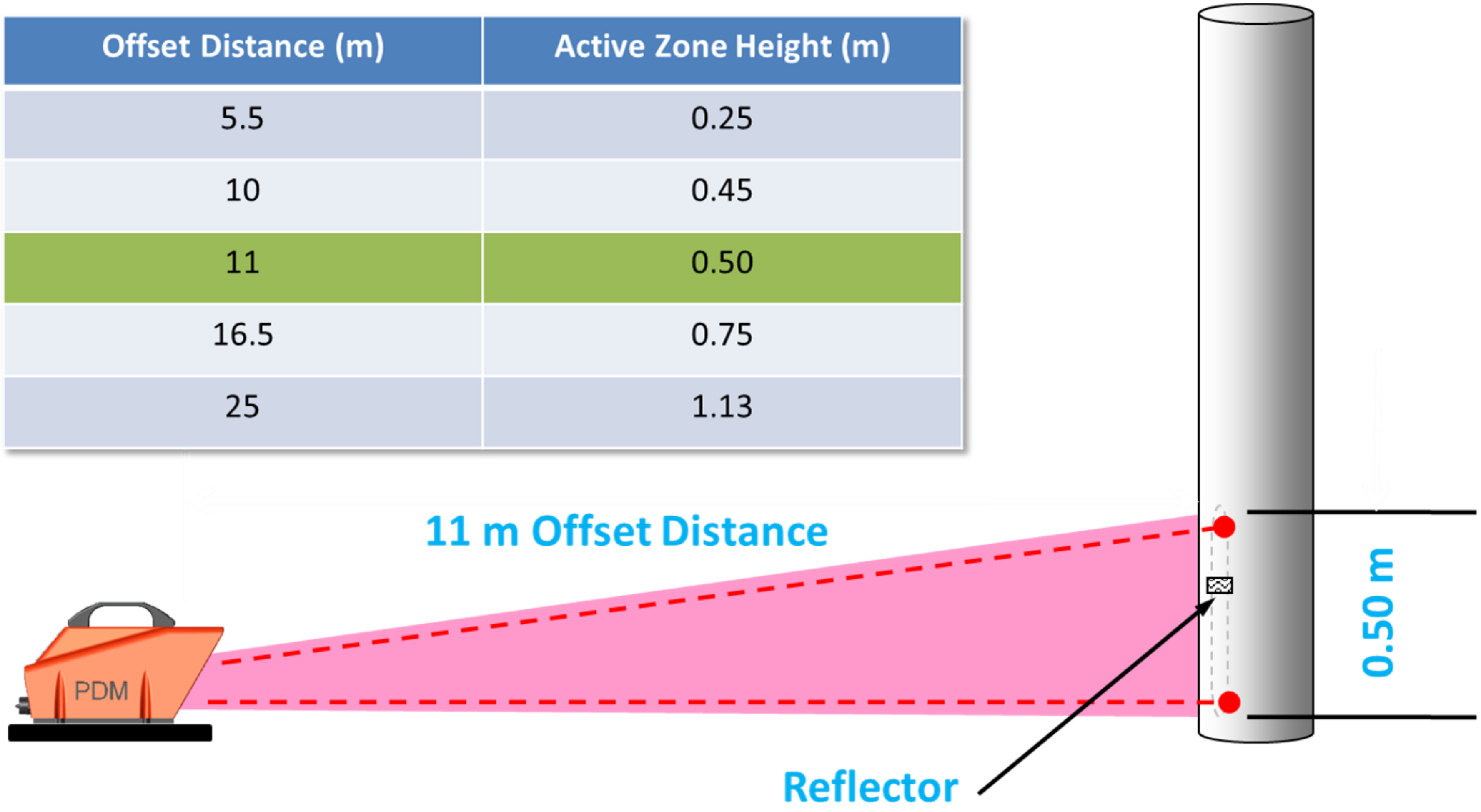
e = efficiency of driving system; W = weight of hammer; H = height of drop;
s = net downward movement: c = elastic rebound

Hamer Type	Efficiency of Hammer / cushioning system (%)	
Hydraulic	65 – 90	X 1.38
Drop (winch – operated)	40 – 55	X 1.375
Diesel	20 – 80	X 4

Traditional Measurement of Set & Rebound

PDM Measurement

Offset Distance (m)	Active Zone Height (m)
5.5	0.25
10	0.45
11	0.50
16.5	0.75
25	1.13

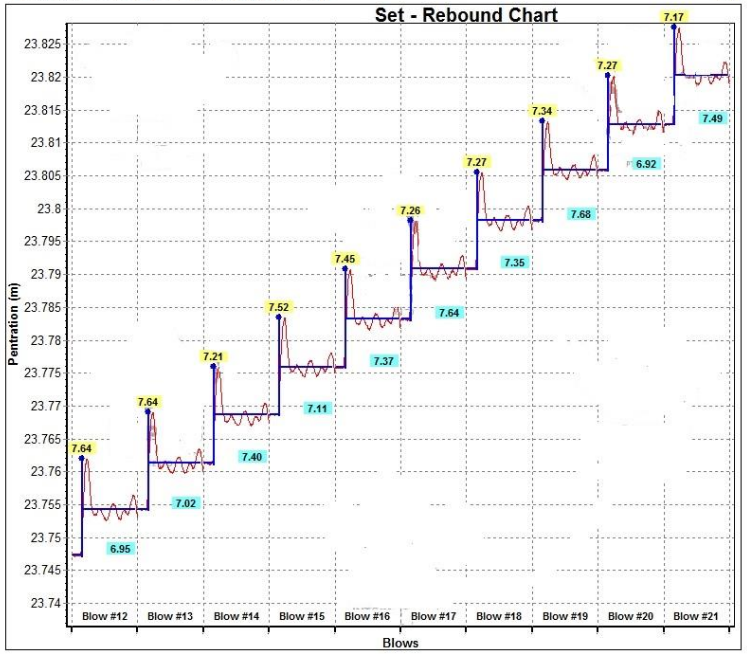


Introduction – PDM the basics

The Pile Driving Monitoring (PDM) is based on LED opto-electronic technology and measures pile set and temporary compression by non-contact measurement from a safe distance. The peak pile velocity can also be calculated.

PILE DRIVING MONITOR RECORD

Company Name : FSG
Client Name :
Project Name : Reported : 02/10/2014 3:51:56 PM
Project Description : PILING Test : 02/10/2014 3:49:43 PM
Pile Number : P45-16 PDM Pile Offset (m): 5.73
Pile Type : Prestressed Concrete Final Penetration at Blow 21 (m) : 23.82
Hammer : NAC 16 TONNE (Custom) Stroke (m) : 0.50



+ Energy

No. Blows : 10/23

Set (mm) : 7.29 V1X (m/s) : 1.57
Rebound (mm) : 7.38 EMX (kJ) : 57
DMX (mm) : 14.67 Capacity (kN) : 3710

Capacity Formula: PDM_V
Energy (EMX) – Velocity (V1X)
EMX=23.26V1X^2+ 0.00V1X+ 0.00
Correction Factor (DRF)
DRF= 0.00SET^2+ 0.00SET+ 1.41

Supervisor : DB Superintendent : BLK

Parameters in RED have been modified POST-SURVEY
Filename : YEPPEN SOUTH BRIDGE 1_P45-16 EOD~1.dbm PDM Serial Number: PJS009239

SPT + PDM measurements

SPT

- 3 X 150mm measured (1 Seating + 2 test drives)
- Count Number of blows for each increment
- N – Value over last 2 test drives

SPT + PDM

- 400 readings / second (G2/ 2015 model is 4,000)
- Over 30,000 readings
- Digital Measurement for SET & ENERGY

PDM set up on site

PDM set up from 2 angles (Hammer + below anvil)

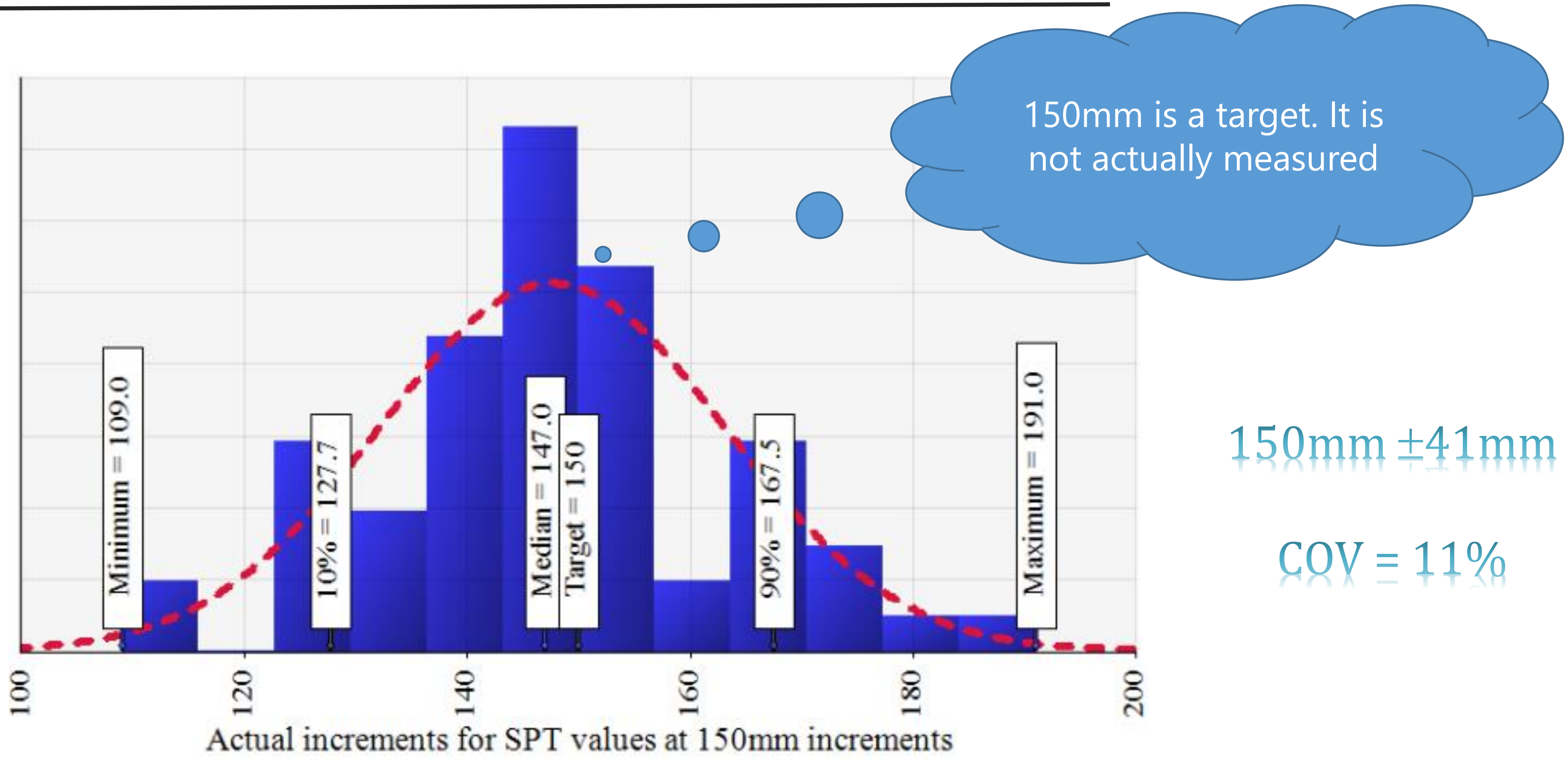
Monitors Hammer

Monitors Rod below anvil

Queensland Government

2 PDMs + PDA SPT analyser (Milton)

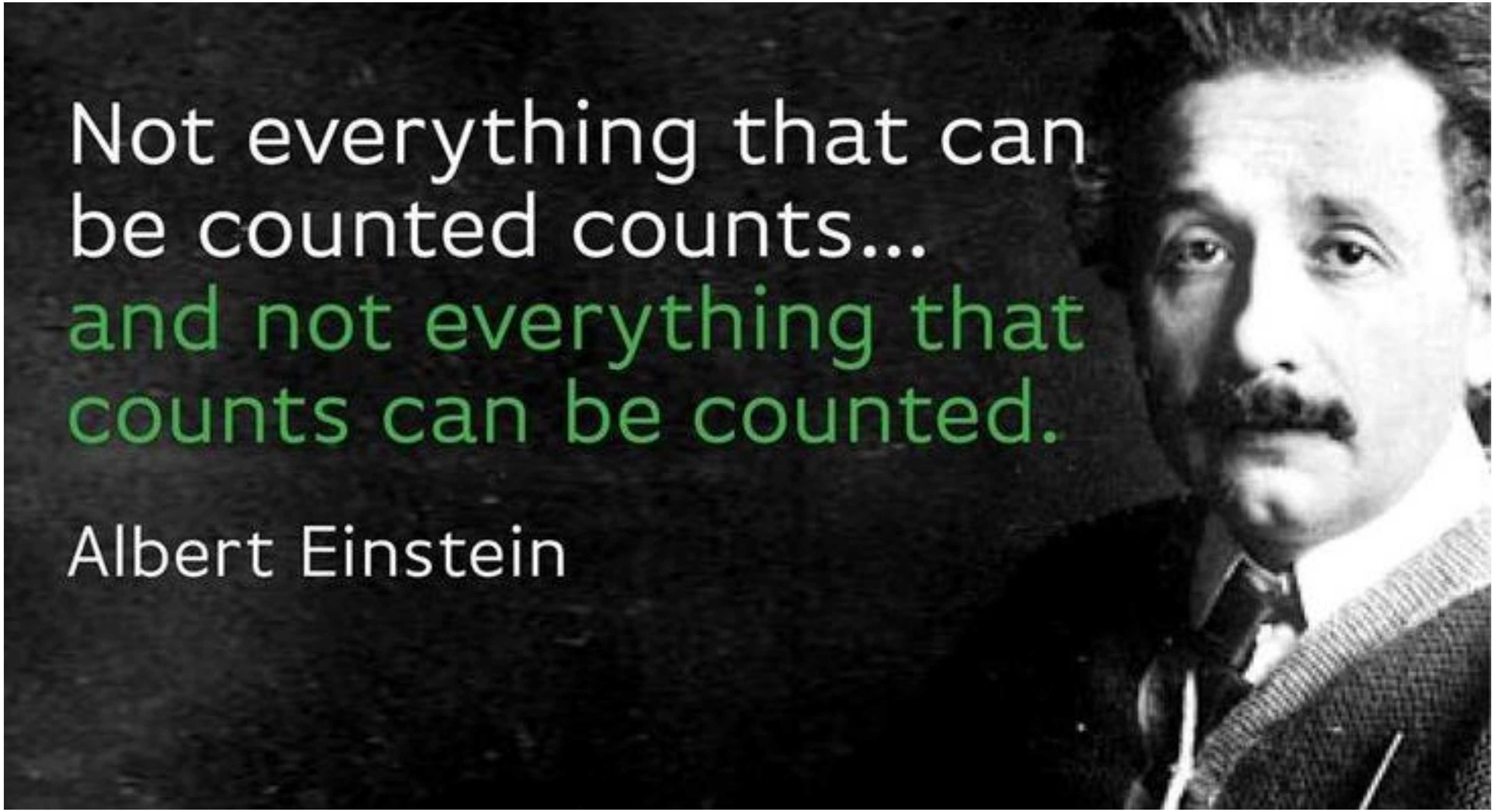
Measurements by eye and digitally compared



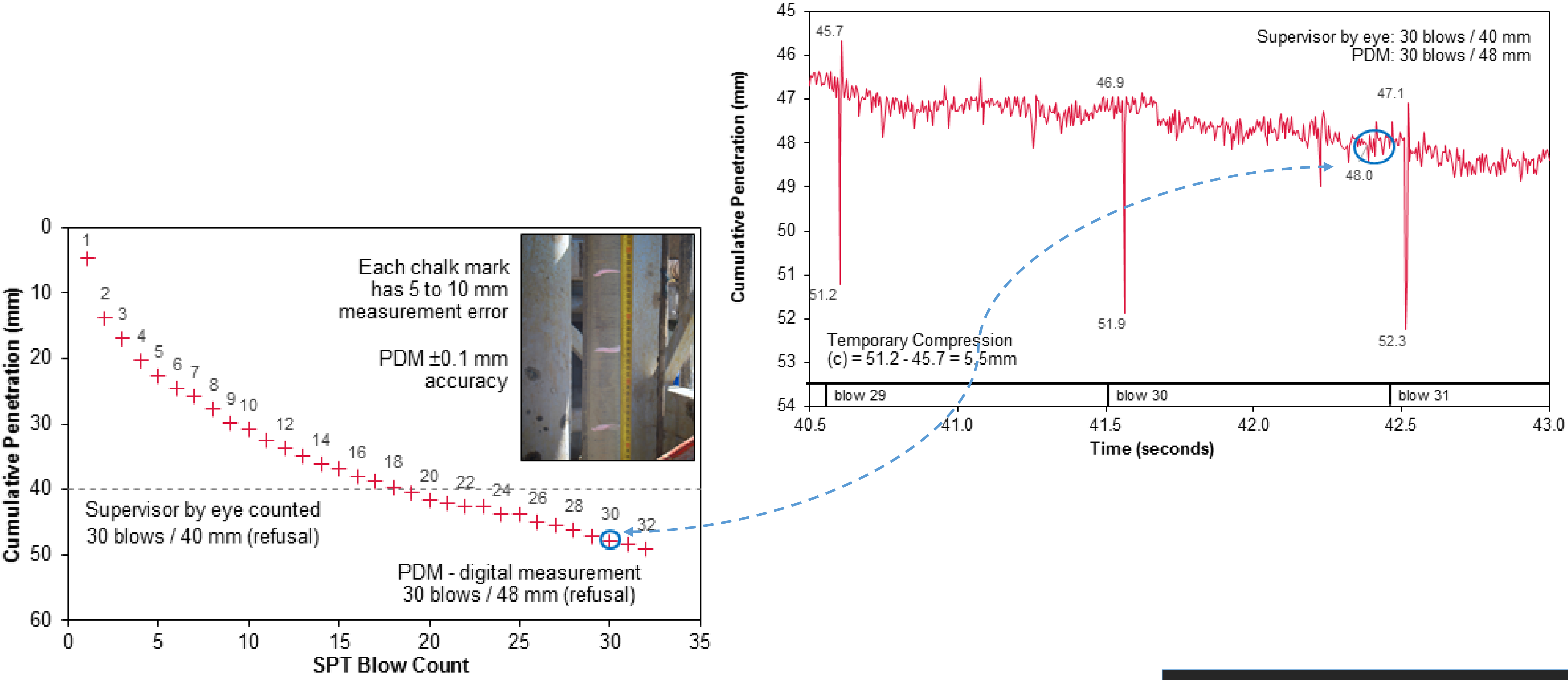
150mm ±41mm

COV = 11%

SPT Counting



Chalk Mark Technology vs Digital Measurements



Energy Transfer

There are many corrections factors to be applied to convert the in-situ N–value to a useful design value. Energy is widely considered the key correction factor. Energy transfer is affected by the type of drill rigs, hammers used, operator skills as well as the ground conditions.

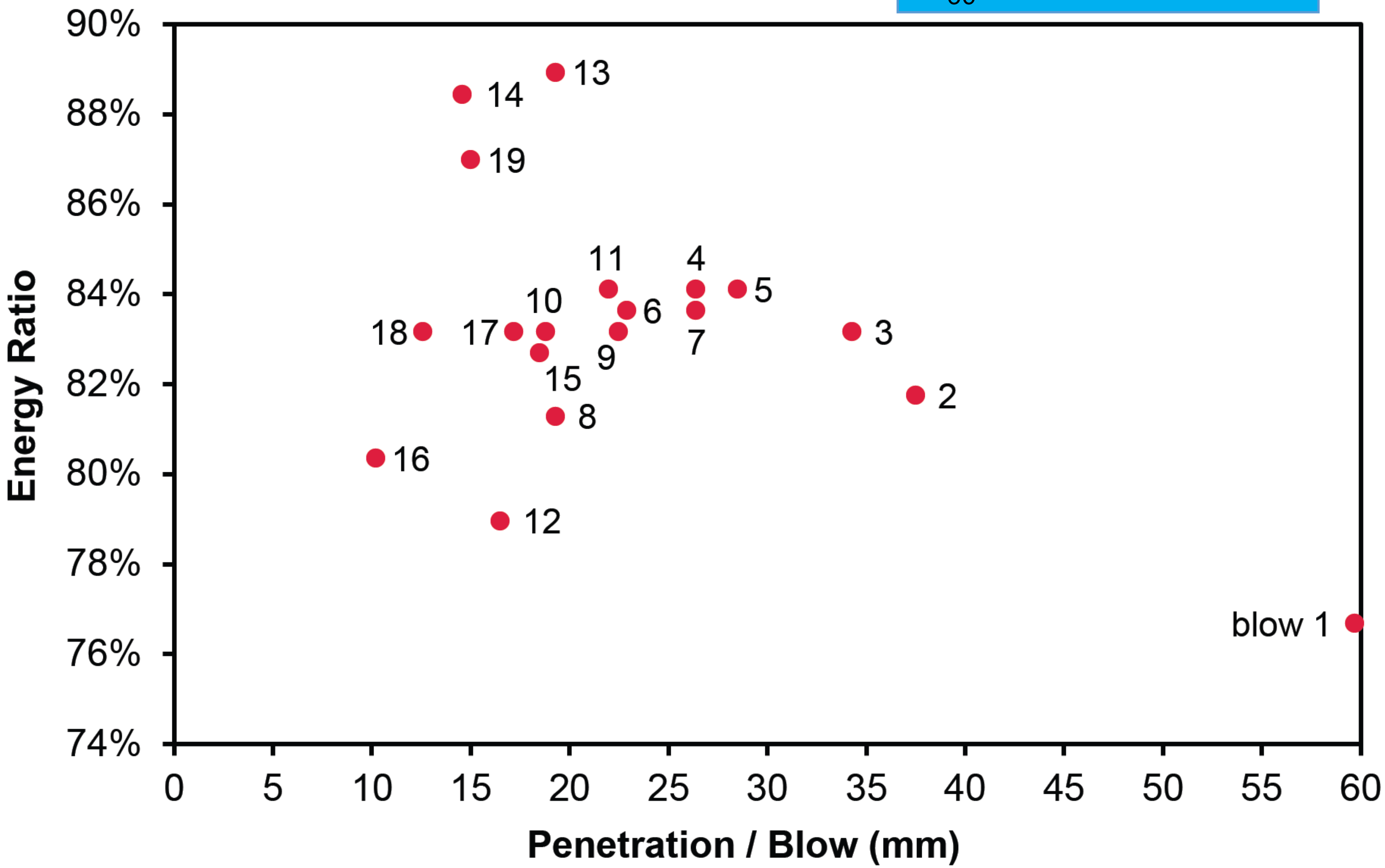
$$N_{60}\,E_{60} = N_{SPT}\,E_{SPT}$$

Australian Standards do not currently specify energy requirements in test
ERGO → energy is not measured.
Any correction (if applied) is based on the international literature.

Variation of Hammer energy ratio for N - value

C139 @ 0.5m : N = 4/6/9 = 15

N_{60} = 1.16 X 15 = 17



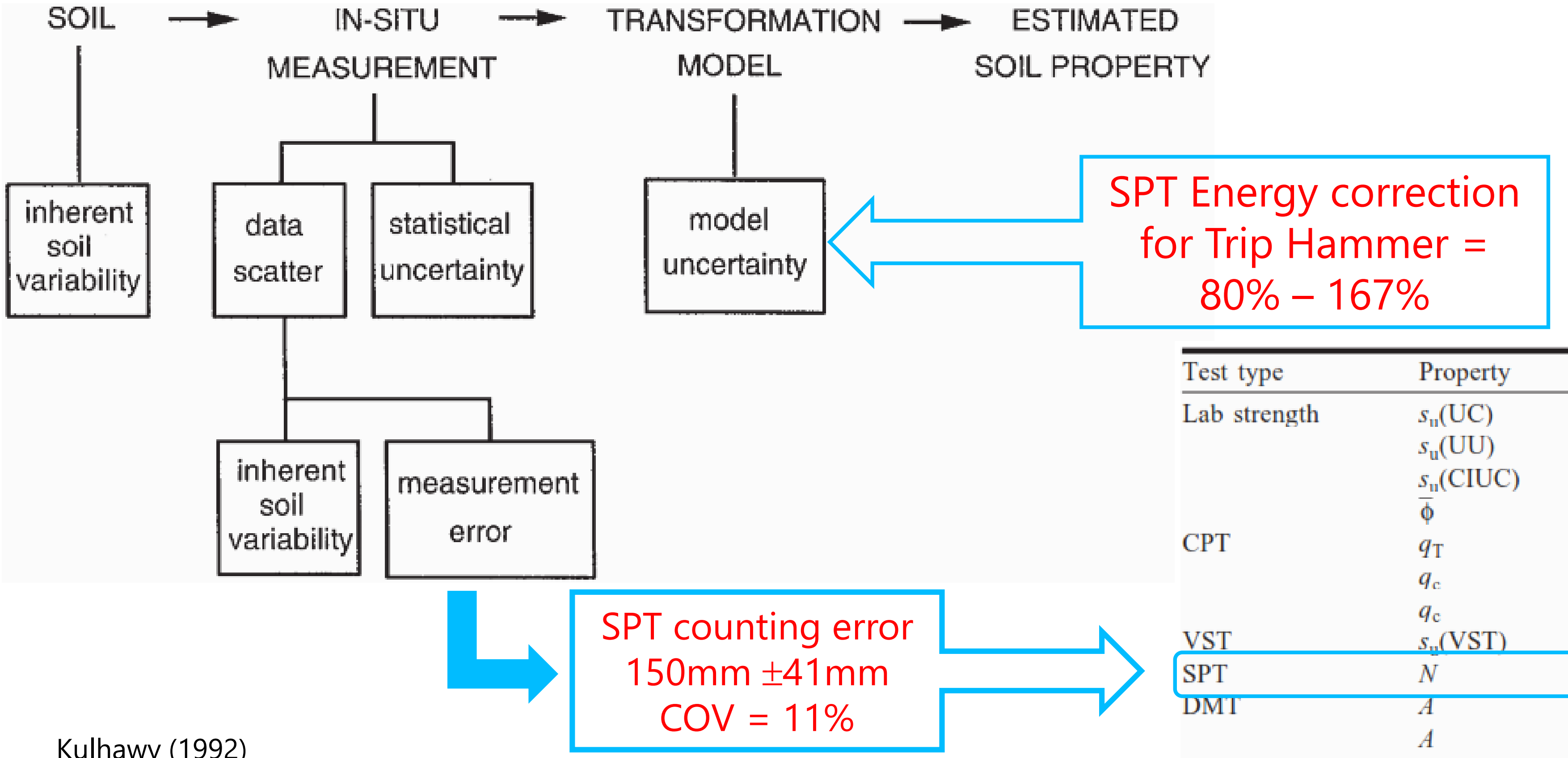
Energy @ Rod is required

Milton N - values without and with correction

ID	Depth (m)	Standard Penetration Test		Average Energy Efficiency – E (%)	Corrected N N_{60}
		Blows	Uncorrected N-value		
BH02	1.00	2, 2, 3	N = 5	71	6
	8.00	1, 4, 4	N = 8	77	10
	9.00	3, 4, 6	N = 10	84	14
	10.00	5, 9, 12	N = 21	81	28
	11.00	10 / 0 mm, HB	N* @ Refusal	90	N* X 1.5

ID	Depth (m) / Material	C_u ~ 5 X N (Stroud, 1988) C_u = 6 X N (Kulhawy and Mayne, 1990)	
		Uncorrected N-value	Corrected N, N_{60}
BH02	1.00 / Alluvial Clay	25 -30 kPa	30 - 36 kPa
	8.00 / Residual Clay	40 - 48 kPa	50 - 60 kPa
	9.00 / Residual Clay	50 - 60 kPa	70 - 84 kPa
	10.00 / Residual Clay	105 - 126 kPa	140 - 168 kPa
	11.00 / XW Phyllite	> 500 kPa	> 750 kPa

Uncertainty in Soil Property Estimates



Kulhawy (1992)

Test type	Property	Soil type	Mean	COV(%)
Lab strength	s_u(UC)	Clay	10–400 kN/m^2	20–55
	s_u(UU)	Clay	10–350 kN/m^2	10–30
	s_u(CIUC)	Clay	150–700 kN/m^2	20–40
	$\bar{\phi}$	Clay and sand	20–40°	5–15
CPT	q_T	Clay	0.5–2.5 MN/m^2	<20
	q_c	Clay	0.5–2.0 MN/m^2	20–40
	q_c	Sand	0.5–30.0 MN/m^2	20–60
VST	s_u(VST)	Clay	5–400 kN/m^2	10–40
SPT	N	Clay and sand	10–70 blows/ft	25–50
DMT	A	Clay	100–450 kN/m^2	10–35
	A	Sand	60–1300 kN/m^2	20–50
	B	Clay	500–880 kN/m^2	10–35
	B	Sand	350–2400 kN/m^2	20–50
	I_D	Sand	1–8	20–60
	K_D	Sand	2–30	20–60
	E_D	Sand	10–50 MN/m^2	15–65

Phoon et al. (1995)

The Final Word

Perhaps it is time for the ubiquitous SPT (1940s procedure) to enter the digital age (2010+).

Visually counting values in 150mm increments is shown to vary and is an “interpretative” number

The field N-Values are useful to show relative change. If Energy is not measured, the value is questionable as a design value.